

Variability of Soft X-ray Spectral Shape: Narrow-Line Seyfert 1 Galaxies versus Broad-Line Seyfert 1 Galaxies

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Abstract. In order to understand how the soft X-ray spectra vary we present the Hardness Ratio 1 versus Count Rates (HR1-CTs) correlation of 8 Narrow-line Seyfert 1 Galaxies (NLS1s) and 14 Broad-line Seyfert 1 Galaxies (BLS1s) obtained during the ROSAT PSPC pointing observations. According to our criteria, six of the NLS1s show a positive HR1-CTs correlation, and seven of the BLS1s display an anti-correlation of HR1 versus CTs. The other 2 NLS1s and 7 BLS1s do not show a clear HR1-CTs correlation. From these we can see that the NLS1s statistically show a different spectral shape variability with flux change from the BLS1s: the spectra of NLS1s become harder as total flux increases while those of BLS1s soften. We attribute the different spectral variations to a strong stable 'soft excess' in NLS1s, while it is weak in BLS1s. For two types of objects, the power law component similarly becomes softer with increasing intensity. These imply that the soft excess originates from the Big Blue Bump and power law emission is from Compton upscattering of UV or Soft X-ray photons. Our results are consistent with what is widely accepted that NLS1s have smaller black hole masses and higher accretion rates than BLS1s.

Key words. galaxies: Narrow-line Seyfert 1 – soft excess; galaxies: Broad-line Seyfert 1 – power law

1. Introduction

Narrow-line Seyfert 1 galaxies (NLS1s), a peculiar group of AGNs, are characterized by their optical line properties: $H\beta$ FWHM is not larger than 2000 km s^{-1} , the $[OIII]\lambda 5007\text{\AA}$ to $H\beta$ ratio is less than 3, and UV-optical spectrum is usually rich in high-ionization lines and Fe II emission multiplets (Osterbrock & Pogge 1985). From the ROSAT All-Sky Survey it was found that about half of the AGNs in soft X-ray selected sample are NLS1s (Grupe 1996); in addition, Boller et al. (1996) revealed that the soft X-ray spectra of NLS1s are systematically steeper than those of Broad-line Seyfert 1 galaxies (BLS1s) and that an anti-correlation exists between the X-ray photon index and the FWHM of the $H\beta$ line, which provides strong evidence for a physical link of continuum emission and the dynamics of the broad line region. Moreover, it was discovered that NLS1s often show stronger X-ray variance than BLS1s (Boller et al. 1996, Leighly 1999a, Papadakis et al. 2001). Some ROSAT (0.1-2 keV) observations revealed dramatic variability with giant flares, with flux increase by a factor of 3-5, within about a day (Boller 2000 for recent review). Best individual examples are IRAS 13224-3809, the flux of which varies about 2 times in 800 seconds (Boller et al. 1997), PHL 1092

(Brandt et al. 1999) and PKS 0558-504 (Gliozzi et al. 2001, Wang et al. 2001). In general, these features are interpreted as the evidence for smaller black masses and higher accretion rate in NLS1s.

In the soft X-ray band below 2.0 keV, two principal components are found in the spectra of AGNs: a non-thermal power law emission which extends to hard X-ray band and a soft excess (typically $< 0.5 \text{ keV}$). The soft excess may be a thermal emission as the high energy tail of the Big Blue Bump (BBB), which is considered as the thermal emission from the hot accretion disk. NLS1s often contain a strong 'soft excess' component above extrapolated hard X-ray power law (Boller et al. 1996, Leighly 1999b). Which component dominates the variability of NLS1s? The extreme soft excess of NLS1s compared to BLS1s makes a first impression that their violent variability may be from the soft excess. If the variability is mainly from the soft excess, NLS1s at brighter states will show softer spectra. And if the variability is mainly from the power law excess, NLS1s at brighter states may show a harder spectrum, since the soft excess dominates the soft band under 0.5 keV. Thus, the spectral variability of NLS1s can be used to check the origin of the variability.

Although much attention was paid to the X-ray variability of NLS1s, most of the papers were on the time scales and amplitude, while seldom on the soft X-ray spec-

tral shape. Spectral hardening during flux increasing was noted in three ROSAT observations of MARK 766 by Leighly (1996). And Page et al. (1999) further pointed out that the power law component of MARK 766 varied violently while the soft excess showed no detectable variability, and that the power law component became softer with increasing flux. Can the properties of MARK 766 be typical of NLS1s? To address the question about the variability of the soft excess and power law component, more NLS1s must be included.

In this paper we report the results of the correlation between Hardness Ratio 1 and Count Rates (HR1-CTs) of 8 NLS1s and 14 BLS1s. BLS1s are better for analyzing the behavior of the power law component since their soft excesses are generally much weaker than those of NLS1s. The 22 objects were all observed with ROSAT/PSPC in pointing mode. In sec. 2 we describe the observations and data reduction. The results are shown in Sec. 3, Sec. 4 contains our discussion; finally we take into conclusion in sec. 5.

2. The observations and data reduction

The data used in this paper are from ROSAT pointed observations of individual objects carried out during the period from days to years, using the X-ray telescope (XRT) on board the ROSAT observatory with PSPC on the focal plane (Trümper 1983). We selected AGNs from cross identification of Veron (1991)'s AGN catalogue with ROSAT pointed catalog. Using the ROSAT public archive of pointed observations, only sources with total X-ray photon counts more than 1000 are selected in order to obtain high quality X-ray spectrum. This yielded 214 AGNs. The data were processed for instrument corrections (such as the vignetting and the dead line effects) and background subtraction using the EXSAS/MIDAS software.

The light curve for each AGN was obtained from original ROSAT observations with time binning of 400 seconds in three energy bands: 0.1-2.4 (total band), 0.1-0.4 (A band), 0.5-2.0 (B band) keV. Then, we picked up 22 Seyfert 1 galaxies or quasars of the 214 objects by the following criteria: 1) For each source the ratio of maximal CTs to minimal CTs is greater than 2, which assure the range of CTs variability is large enough; 2) The data points is not too scarce (> 5) and they distribute in one diagram consecutively; 3) HR1 error is small ($< 40\%$). These sources are of different types of AGNs, including 8 NLS1s, 14 BLS1s/QSOs.

3. Analysis of spectral shape variability

3.1. The results of HR1-CTs correlations

All these X-ray count rates in 0.1-2.4 keV band were gained from original ROSAT observations with time binning of 400 s. In addition, 4 energy bands are shown: A 0.1-0.4 keV, B 0.5-2.0 keV, C 0.5-0.9 keV, D 0.9-2.0 keV.

The standard hardness ratios, HR1 and HR2, for ROSAT-PSPC data are defined as:

$$HR1 = \frac{B - A}{B + A}, HR2 = \frac{C - D}{C + D} \quad (1)$$

"A" band is the most sensitive to the variability of the soft excess in the four ROSAT bands. The variability of the soft excess will show in the correlation between HR1 and count rates. In order to distinguish different variation trend of each object we fit the data through a linear formula ($HR1 = a + b \times CTs$): When the slope b is a positive or negative value and its relative error is less than 50%, we think it has a positive or negative correlation; The other instances are of random or no clear correlations. The results of the HR1-CTs correlation of 8 NLS1s and 14 BLS1s/QSOs are listed in Table 1 and plotted in Fig. 1-3. The correlations are summarized as the following:

1. For eight NLS1s in the sample, six of them, MCG-6.30.15, MARK 335, PG 1404+226, MARK 766, WAS-61 and NGC 4051, show a positive HR1-CTs correlation. Both PG 1211+143 and TON S180 do not show any clear variation trend.
2. Seven of the fourteen BLS1s, NGC 7469, MARK 841, NGC 5548, NGC 3031, GQ COM, 3C 273.0 and IV ZW 29, demonstrate a negative HR1-CTs correlation. The rest objects show random variability.

NLS1s, as a group, statistically show the trend that the spectrum becomes harder when the count rates increase. Those BLS1s who show a clear HR1-CTs correlation all present an opposite trend, in other words, their soft X-ray spectra become softer with increasing flux.

In addition, we note that there exist some particular points in the HR1-CTs plot of several NLS1s such as NGC 4051 and WAS 61, which display a very high value of HR1 as the count rates are low, contrary to the statement above. A sudden fading of soft excess or a violent enhance of the power law component might interpret this hardening in the low state, but detailed analyses will be necessary, which is beyond the scope of this paper.

3.2. The variability: the soft excess vs. the power law component

Which component dominates the violent variability of NLS1s? If the violent variability of NLS1s is mainly from the soft excess, the ROSAT A band (0.1-0.4 keV) will be expected to change more than the B band (0.5-2.0 keV), and hence a negative HR1-CTs correlation is expected. The statistically positive HR1-CTs correlation of NLS1s shown above implies that the soft X-ray variability of these NLS1s mainly comes from the power law component, not from the soft excess. This is in agreement with the result from the detailed analysis about MARK 766 by Page et al. (1999), who found that there was no detectable change of the soft excess while the power law component varied.

Table 1. Spectral shape variation of our selected NLS1s and BLS1s. Positive: the HR1-CTS relation is positive, Negative: the HR1-CTS relation is negative, None: the HR1-CTS relation is random. S1n: Narrow-line Seyfert galaxy, Sy1.0 (1.2, 1.5, 2.0): Seyfert 1.0 (1.2, 1.5, 2.0), Q: Quasar.

ROSAT name (1RXPJ)	Other name	RA (2000)	DEC (2000)	z	Type	HR1-CTS correlation
133554-3417.2	MCG-6.30.15	13 35 53.3	-34 17 48	0.008	S1n	Positive
000619+2012.4	MARK 335	00 06 19.4	20 12 11	0.025	S1n	Positive
140621+2223.7	PG 1404+226	14 06 22.1	22 23 42	0.098	S1n	Positive
121827+2948.8	MARK 766	12 18 26.6	29 48 46	0.012	S1n	Positive
124212+3317.0	WAS 61	12 42 11.3	33 17 06	0.045	S1n	Positive
120310+4431.9	NGC 4051	12 03 09.5	44 31 52	0.002	S1n	Positive
005719-2222.7	TON S180	00 57 19.0	-22 22 47	0.062	S1n	None
121417+1403.3	PG 1211+143	12 14 17.5	14 03 12	0.085	S1n	None
230316+0852.2	NGC 7469	23 03 15.5	08 52 26	0.017	Sy1.5	Negative
150401+1026.3	MARK 841	15 04 01.1	10 26 16	0.036	Sy1.5	Negative
141759+2508.2	NGC 5548	14 17 59.5	25 08 12	0.017	Sy1.5	Negative
095532+6903.9	NGC 3031	09 55 33.1	69 03 54	0.000	Sy1.5	Negative
120441+2754.0	GQ COM	12 04 42.0	27 54 11	0.165	Sy1.2	Negative
122906+0203.2	3C 273.0	12 29 06.6	02 03 08	0.158	Sy1.0	Negative
004215+4019.7	IV ZW 29	00 42 16.0	40 19 36	0.102	Sy1.0	Negative
122144+7518.6	MARK 205	12 21 44.3	75 18 39	0.070	Sy1.0	None
161357+6543.0	MARK 876	16 13 57.0	65 43 08	0.129	Sy1.0	None
132158-3104.2	K08.02	13 21 58.1	-31 04 10	0.045	Sy1.5	None
194240-1019.4	NGC 6814	19 42 40.5	-10 19 24	0.005	Sy1.5	None
121710+0711.5	NGC 4235	12 17 09.8	07 11 29	0.007	Sy1.2	None
092248+5120.8	Q 0919+515	09 22 46.9	51 20 39	0.161	Sy1.0	None
121920+0638.6	PG 1216+069	12 19 20.2	06 38 39	0.334	Q	None

What is the spectral behavior of the power law component? Do NLS1s and BLS1s follow the same rule? The results about the BLS1s are better to answer the first question since the power law component generally dominated the soft X-ray emission of BLS1s. We have showed that the spectra of all the seven BLS1s showing clear HR1-CTS correlation become softer with increasing flux. For these BLS1s their power law components get softer when they are brighter. Our simple analysis of the HR1-CTS correlation of NLS1s could not reveal this question clearly and directly. Detailed study about Mark 766 by Page et al. (1999) revealed that the power law component becomes softer when it becomes brighter, while variability of the soft excess and neutral absorbing column is not detected. The fact that the power law component becomes softer as it becomes brighter also was found in the cases of NGC 4051 and MCG 06-30-15 (Matsuoka et al. 1990, Kunieda et al. 1992, Pounds et al. 1986, Papadakis & Lawrence 1995). Therefore, if MARK 766, NGC 4051 and MCG 06-30-15 are typical examples for NLS1s, the power law components of both NLS1s and BLS1s vary in the same way. This implies that the power law components of both NLS1s and BLS1s have the same physical origin. Two popular models for the power law X-ray component of radio quiet Seyfert galaxies, both of which are based on Compton upscattering of UV or soft X-ray photons from an accretion disk or optically thin plasma, predict that in the variation of a single source the power law slope is softer as the power law flux is higher (Done & Fabian 1989, Torricelli-Ciamponi & Courvisier 1995), exactly consistent with what we have found.

As shown in MARK 766, NGC 4051 and MCG 06-30-15, it is very interesting to note that, although the power law component becomes softer, their total spectra of NLS1s get harder with increasing flux. We suggest

here that the properties of the soft excess take charge of the spectral variability difference between the NLS1s and BLS1s. We take the assumption that, for both NLS1s and BLS1s, the power law component gets softer with increasing flux, and the soft excess remains almost stable during the time scale of the observations. For typical NLS1s, the A band is dominated by the giant thermal soft excess, and B band is dominated by the power law component. The increase of the power law component will change the B band relatively more than the A band, since the A band is dominated by the stable soft excess. Therefore, although the increase of the power component makes the power law component softer, it turns out a harder spectrum when the power law component combines with the soft excess. For typical BLS1s, the total spectrum is dominated by the power law component, and thus behaves just as the power law component. For the NLS1s and BLS1s without clear HR1-CTS correlation, we guess that they occupy marginal soft excess.

4. Discussion: The X-ray properties of AGNs and the nature of the soft X-ray excess

4.1. The origin of the soft excess emission

Two kinds of models were proposed for the origin of the soft excess emission. One is that the soft excess is the high-energy tail of the big blue bump, which is considered as the thermal emission from the hot accretion disk (Ross, Fabian & Mineshige 1992). The other is that the soft excess is from reprocessing of the power law component by optically thin corona (Guilbeit & Rees 1988), or by the surface of the accretion disc (Ross & Fabian 1993). The variability properties of the soft excess and the power law component are useful to check these models.

We have showed that the soft excess is more stable than the power law component. This is consistent with the BBB origin of the soft X-ray excess. The BBB may have a longer variability time scale than the power law X-ray emission (Done et al. 1990). To survey the reprocessing models, the corona, or the accretion disc has to be large enough so that there is no obvious variability of the soft excess following the violent variation of the power law component during the ROSAT observations. It implies that the accretion disc, for its small size, will not be taken as the reprocessing mirror. In addition, the soft excess spectrum can be well fitted by one or two black body spectra, and hence is consistent with the shape expected from the high-energy tail of a hot accretion disk (e.g. Ross, Fabian & Mineshige 1992). Therefore the BBB is the most promising origin of the soft excess emission.

4.2. The X-ray properties: NLS1s versus BLS1s

Although they were defined by Osterbrock and Pogge (1985) according to their peculiar optical properties, NLS1s, compared to BLS1, show their most outstanding properties in the soft X-ray band. The first, NLS1s statistically have steeper X-ray spectra than BLS1s. The second, NLS1s often show shorter and stronger X-ray flux variability than BLS1s. The third, as found in this paper, the soft X-ray of NLS1s statistically become harder during total flux increase, whereas BLS1s often get softer.

The behavior of the soft excess takes charge of both the first and the third differences between NLS1s and BLS1s. The high L/L_{Edd} is popularly accepted as the explanation for the strong soft excess emission of NLS1s. It was first proposed by Pounds et al. (1995), who noted a possible analogy of AGNs to Galactic Black Hole candidates whose soft X-ray spectra become steep in their high state. High accretion rate and thus high disk temperature cause the BBB to shift towards higher energies, so the high-energy tail of the BBB is apparent as the unusually strong and steep soft X-ray excess. Both high L/L_{Edd} and steep soft X-ray spectrum are also beneficial to explain the narrow widths of the emission lines in NLS1s. If the Broad Line Region (BLR) scales as $L^{1/2}$ and the emission clouds are gravitational virialized around the central massive BH, higher luminosity will keep the emission line clouds in BLR farther away from the center, and hence smaller velocity dispersion produces narrower lines. Furthermore, Wandel and Boller (1998) suggested that AGNs with steeper X-ray spectra have stronger ionizing power, and hence have larger BLR and narrower emission lines than flat-spectrum AGNs with comparable luminosity.

The small black hole mass is considered as the driver for the violent and short-time scale variability of NLS1s (Boller et al. 1996, Laor 2000). For the sample of Turner et al. (1999), Laor (2000) found a strong correlation between σ_{rms}^2 and M_{BH} , which was even stronger than the correlation between σ_{rms}^2 and $H\beta$ FWHM. The tight cor-

relation between σ_{rms}^2 and M_{BH} may be understood as the correlation between the variability and the size of the X-ray emitting region, which is supposed to scale with the mass of black hole. The results of reverberation mappings of AGNs have made it possible to estimate the mass of black hole with the $H\beta$ FWHM and luminosity, i.e. $M_{\text{BH}} \propto \text{FWHM}^2 L^\alpha$, where α has the value of 0.5 or 0.7 from different samples (Peterson & Wandel 1999, Wandel, Peterson & Malkan 1999, Kaspi et al. 2000). NLS1s have the smallest black hole in the type 1 Seyferts/QSOs because of their narrowest $H\beta$ line (see Wandel et al. 1999, and Laor 2000).

5. Conclusions

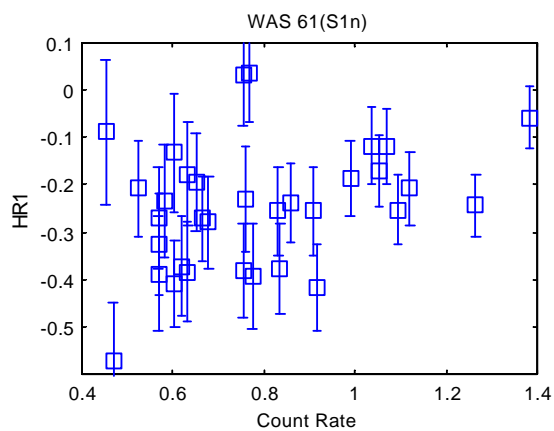
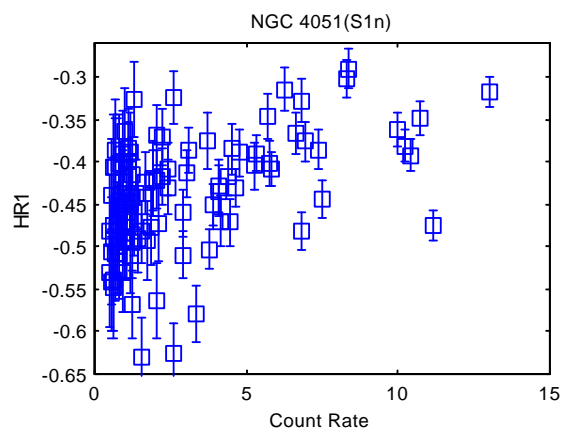
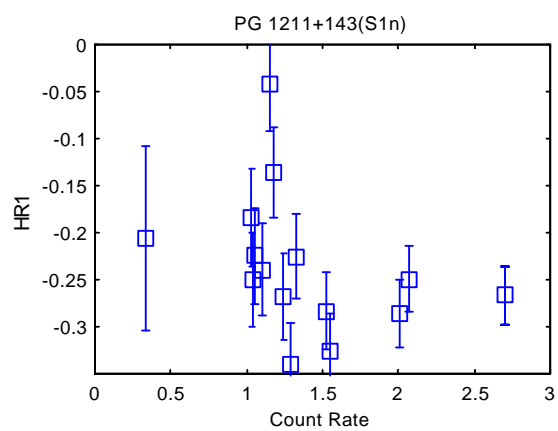
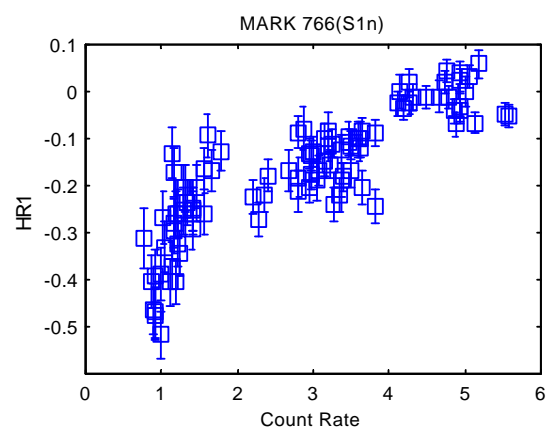
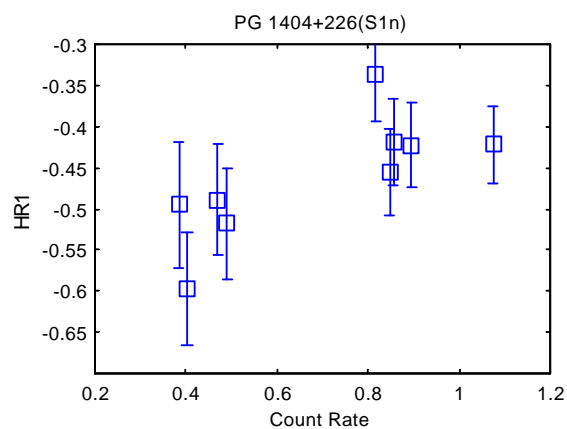
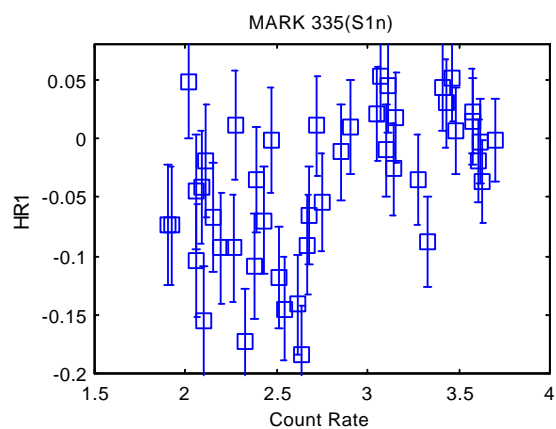
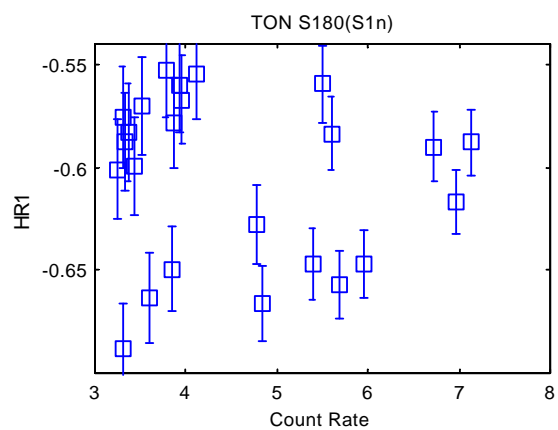
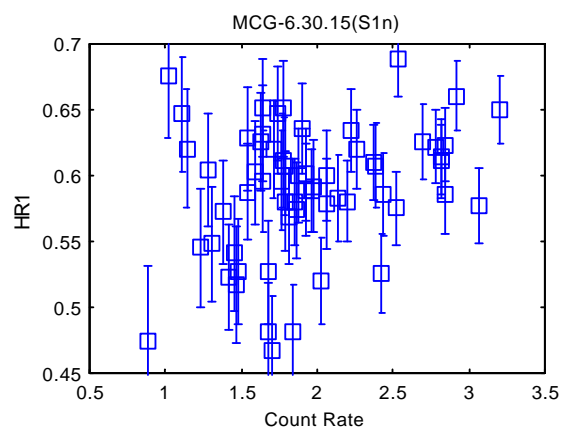
We have presented spectral shape variability analysis of 22 Seyfert 1 galaxies by showing the HR1-CTs relation and found that 6 NLS1s display a positive HR1-CTs correlation in the sense that their spectra harden during overall flux increase, while 7 BLS1s demonstrate an anti-correlation, opposite to NLS1s. All the rest objects do not demonstrate any evident relation of HR1 versus CTs. The different spectral shape variability with increasing intensity can be due to a strong stable soft excess below 0.5 keV in NLS1s, while it is weak in BLS1s. At the same time, both types of objects share a common variable power law component, which softens during its flux increase. These results support the origin of soft excess from the BBB and the power law based on Compton upscattering of UV or soft X-ray photons from an accretion disk or optically thin plasma. Moreover, the different spectral variation is consistent with what is expected if NLS1s have smaller Black Hole masses and higher accretion rates. Thus, the distinct spectral variation trends may be characteristic of BLS1 and NLS1s.

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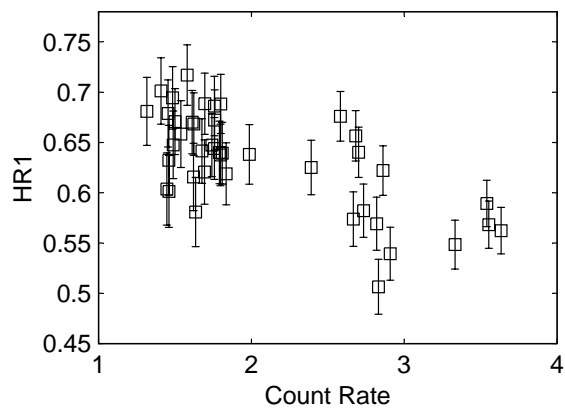
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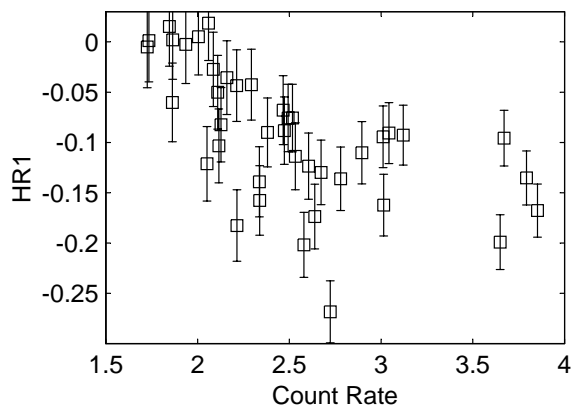
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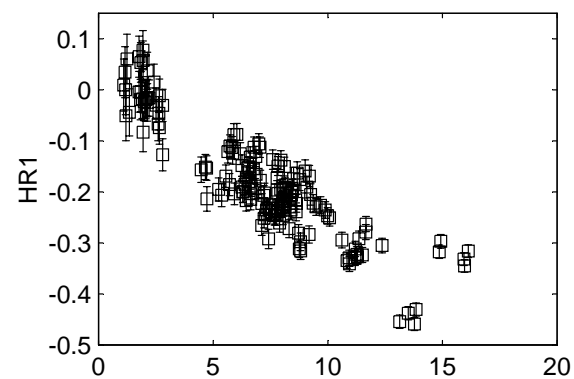
NGC 7469(Sy1.5)



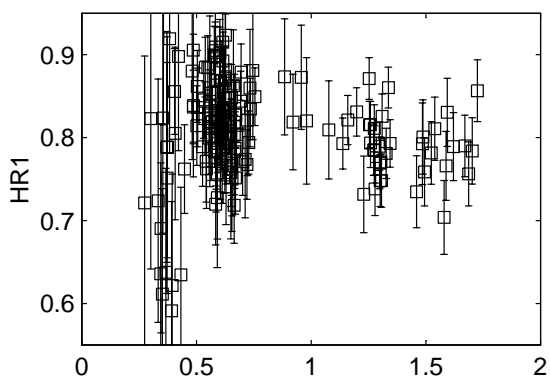
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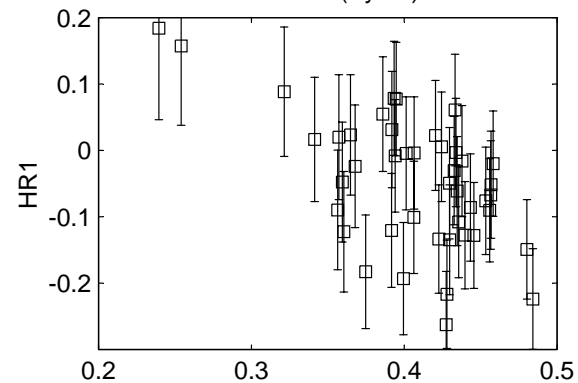
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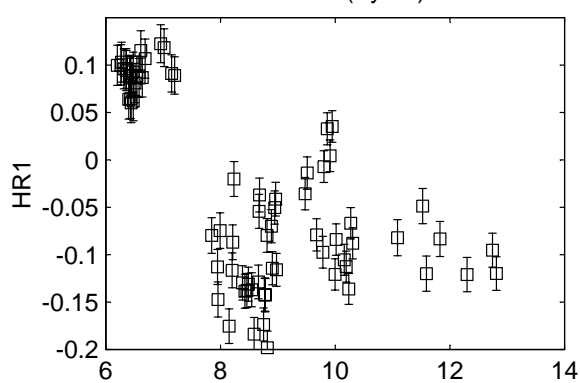
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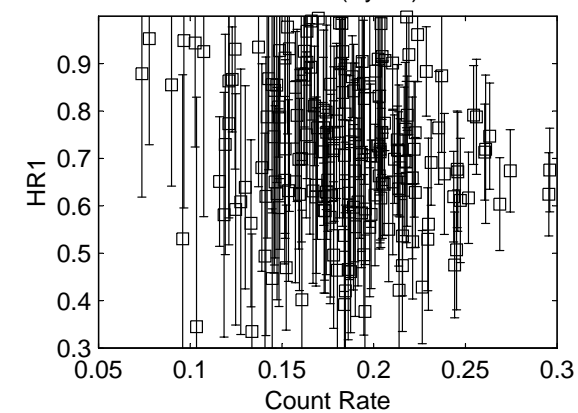
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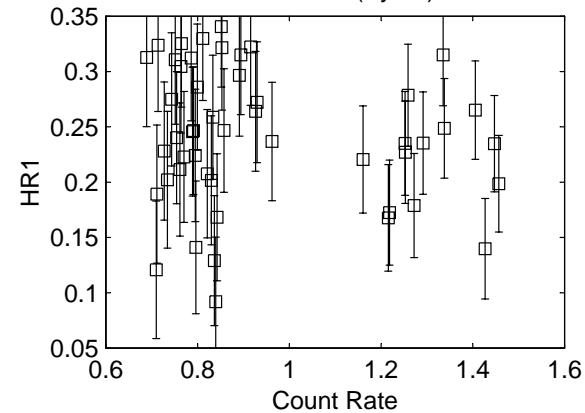
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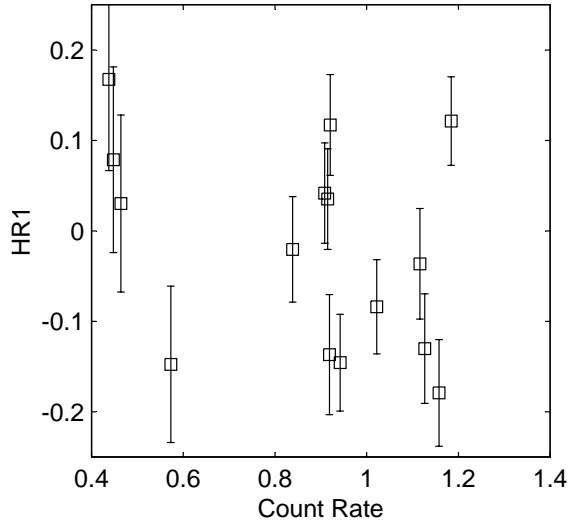
IV ZW 29(Sy1.0)



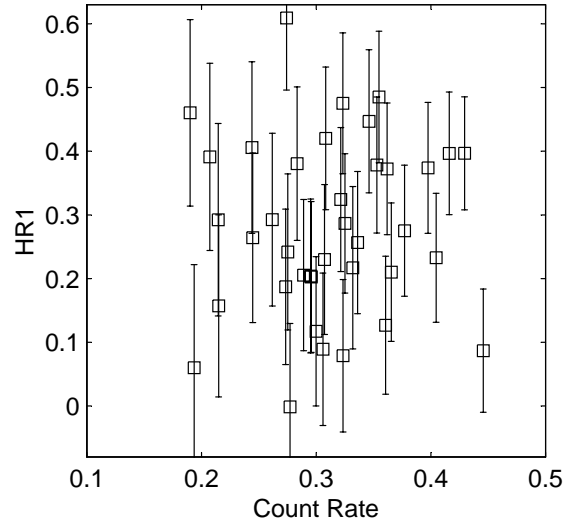
MARK 205(Sy1.0)



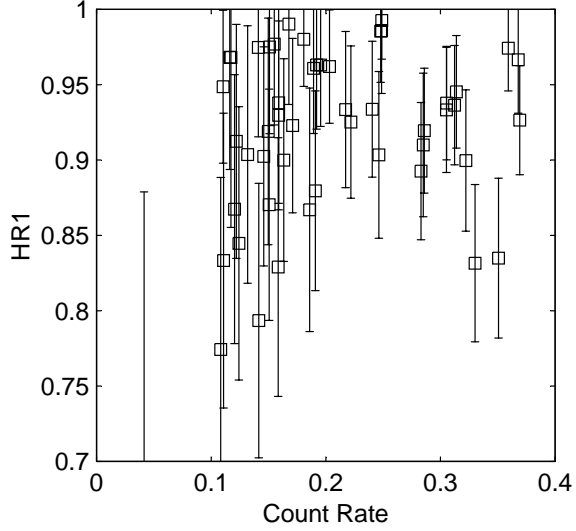
MARK 876(Sy1.0)



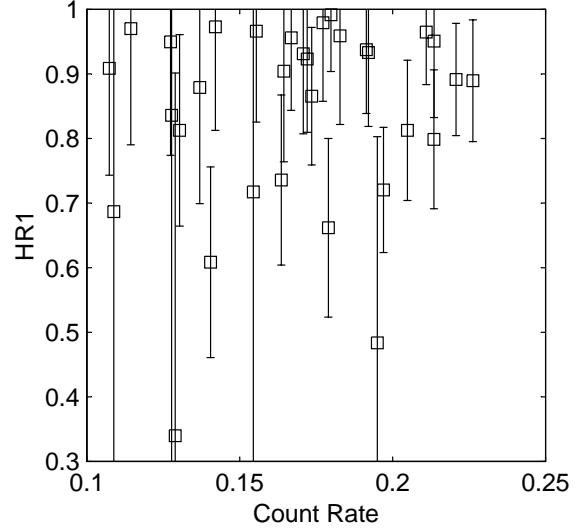
K O8.02(Sy1.5)



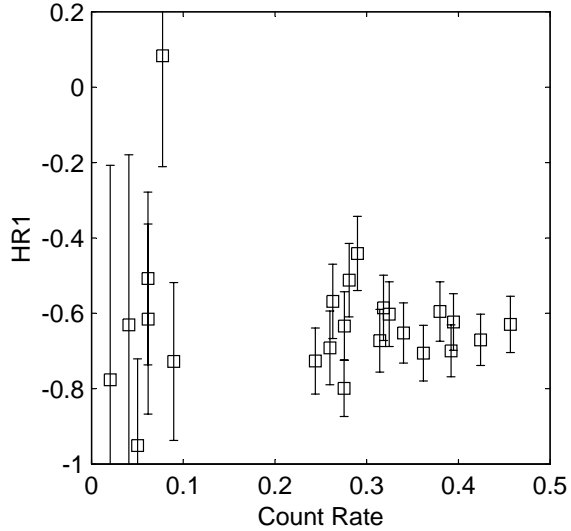
NGC 6814(Sy1.5)



NGC 4235(Sy1.2)



Q 0919+515(Sy1.0)



PG 1216+069(Q)

